# Comment on "Relation to Solar Activity of Intense Aurorae in Sunlight and Darkness"

**by P. T. Newell, C.-I. Meng and S. Wing**

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We applaud the excellent effort and far-reaching results of Newell et al. (1998)[1]. We agree with their statement that "great storms that happen a few times a year contribute only negligibly to the total energy input into the upper atmosphere," and that the oldest documents[2] which "found positive correlations between sunspot numbers and frequency of aurora" were somewhat misleading because those auroral observations were based on relatively rare midlatitude "great aurora". However, we disagree with their conclusion that "the number of intense aurora in darkness is uncorrelated with solar activity". We will show that there is a correlation between nightside aurora and sunspot number, but often with a large phase lag. We will argue that under certain conditions, the energy input into the upper atmosphere can be greater during the declining phase of the solar cycle than during solar maximum or one or two years after solar maximum.

As Newell et al. have argued, intense aurorae occur quite frequently in the nightside (from 2200 to 0200 local time). These intense aurorae occur in discrete events called auroral substorms[3]. Substorms are well known to be caused by interconnection between interplanetary magnetic fields and the earth's magnetic fields. When the interplanetary magnetic field is directed southward, the interconnection with the Earth's northward directed field[4] leads to solar wind energy injection into the magnetotail and then the energy eventually goes into the nightside atmosphere in the form of precipitating energetic electrons, resulting in aurorae.

There are two main solar/interplanetary phenomena that are strongly solar cycle dependent: coronal mass ejections[5] and high speed corotating streams[6]. Coronal mass ejections (CMEs) are impulsive events that occur primarily at and near solar maximum[7]. The maximum rate of solar flares and CME occurs one or two years after solar maximum. The intense magnetic fields in the piled-up sheath and the intense field of the interplanetary CME proper can cause intense magnetic storms[8] and midlatitude auroras at Earth, as discussed previously. However, these events are relatively rare and contribute negligibly to the total energy deposition into the atmosphere, as discussed by Newell et al. (1998).

The second type of interplanetary phenomenon are high-speed streams with velocities of 750 - 800 km $s^{-1}$. These streams emanate from coronal "holes"[9], the latter which are so named because they are "dark" regions of the sun when viewed in soft-x-rays[10]. The coronal holes can be long-lasting, so that with each 27-day rotation period of the sun, the Earth's magnetosphere gets sprayed with this high-speed stream. The NASA/ESA

Ulysses mission has shown the high-speed streams contain very large directional (transverse) fluctuations of the interplanetary magnetic fields called Alfvénic waves[11-13]. The transverse amplitude of the waves are the same size as the magnetic field magnitude.

During solar maximum, the coronal holes are confined primarily to the sun's polar regions and are of smaller area (or they can disappear altogether). Since the high-speed solar wind comes radially outward from the sun, these streams would not hit the Earth's magnetosphere. However, during the declining phase of the solar cycle or during solar minimum, the polar holes become enlarged and they descend to the solar equator and beyond. This happens for the holes at both poles. Thus, under certain circumstances, the two coronal holes can occupy much of the solar equator, so the Earth's magnetosphere is almost always embedded within a high-speed solar wind stream. This situation happened in 1973-1975 (the two solar maxima were in 1969 and 1980). The Alfvén waves had random $B_Z$ (and other directions as well) fluctuations. When the fields were southward (negative $B_Z$ values, by convention), solar wind energy transfer led to auroral substorms. When $B_Z$ was directed northward, there was no substorm activity. An example of the former is shown in Figure 1. Because the Earth was continually embedded in these fluctuating magnetic fields, auroral substorms were occurring one after the other in a continuous string of geomagnetic activity. This activity is called High Intensity Long-Duration Continuous Auroral activity, or the acronym HILDCAAs[14-15].

Assuming that the storm time ring current energy contribution is negligible over a yearly average, we calculate the average AE value for 1974 and 1979-1981 (the actual solar maximum peaks in sun spot had a dual maxima). We find that $\overline{AE}_{1974} = 281\,\mathrm{nT}$ and $\overline{AE}_{1979} = 221\,\mathrm{nT}$. Thus, there was more energy input into the auroral zone atmosphere during a declining phase year (1974) than during solar maximum (1979).

Is this the general case? In Figure 2, we show the sunspot number, AE and $D_{ST}$ for the years 1957 through 1989. This is all of the data that are available. From this figure, one can again note that 1973-1975 auroral activity is higher than the solar maximum years 1969 and 1979-1981. The large storms (negative $D_{ST}$) are spread widely (1966-1971), but are centered roughly about solar maximum. Thus, for this cycle, the auroral (AE) peak occurs well separated from the storm $D_{ST}$ peak and also from solar maximum.

The situation is more complex for the other two solar maxima. There is a broad $D_{ST}$ maximum from 1957 to 1961. This is more-or-less in phase with the AE maximum. Thus the peak $D_{ST}$ and AE activities occur at solar maximum and in the start of the descending phase for this cycle.

The last sunspot maximum in the data set occurs in 1979. The peak $D_{ST}$ activity is 1981-1982. This trails the solar maximum by 2-3 years as in the canonical picture. The peak AE activity is 1981-1984, in the descending phase of this solar cycle. We speculate that this is due to Alfvén waves and corotating high-speed streams which are present in the descending phase of the solar cycle. This is similar to the 1973-1975 AE maximum.

Final Comments

We have touched on only one portion of the Newell, et al. article. However, in keeping with their theme that the "lore" that greater auroral arc activity occurs during solar maximum is incorrect, we modify their statements somewhat. We argue that there is a solar cycle dependence on nightside auroral activity, but that the maximum in activity occurs 3 or even up to 6 years after solar maximum. The peak in auroral activity is due to continuous substorms generated by $B_Z$ fluctuations in Alfvén waves in high-speed coronal hole streams.

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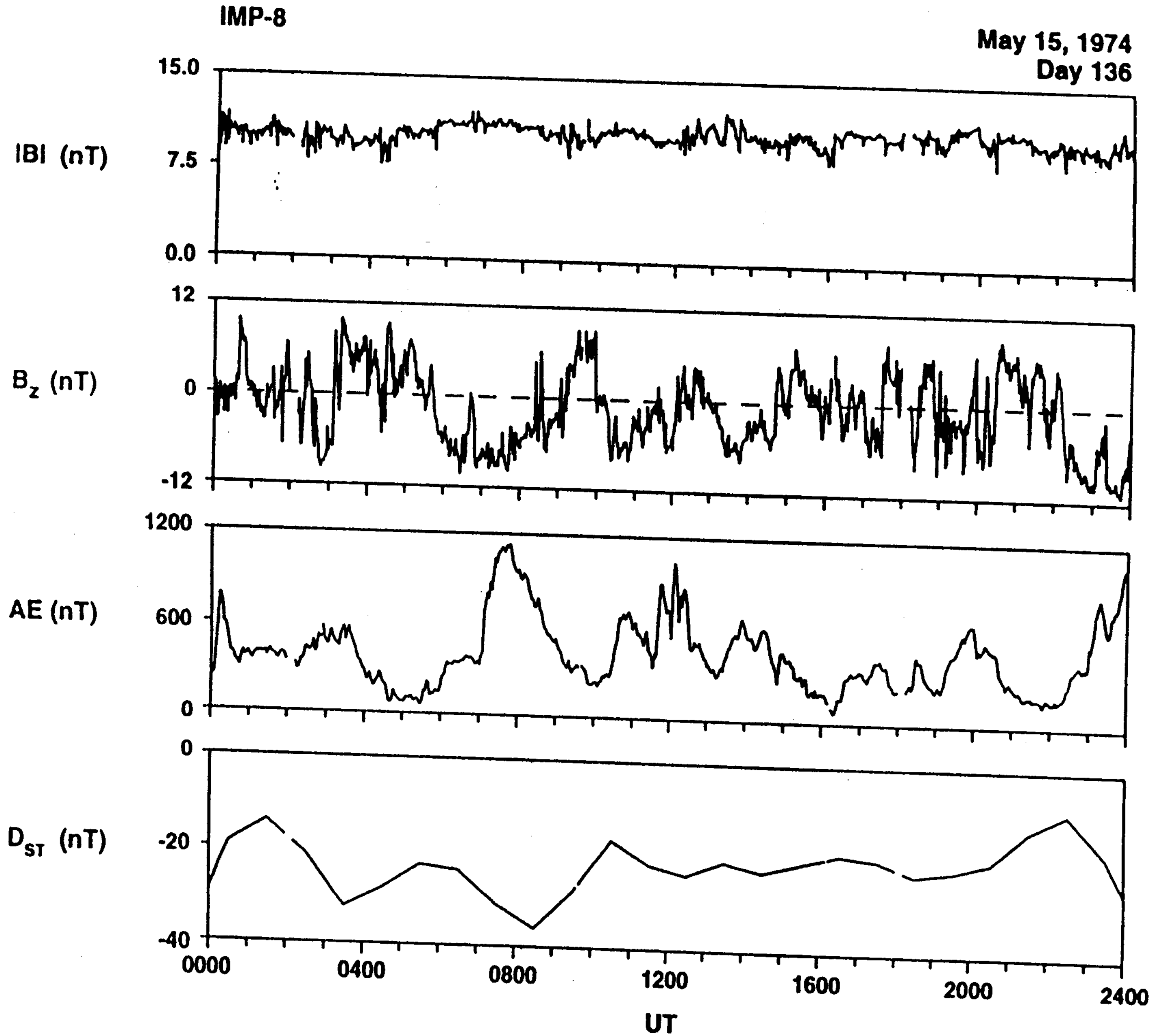
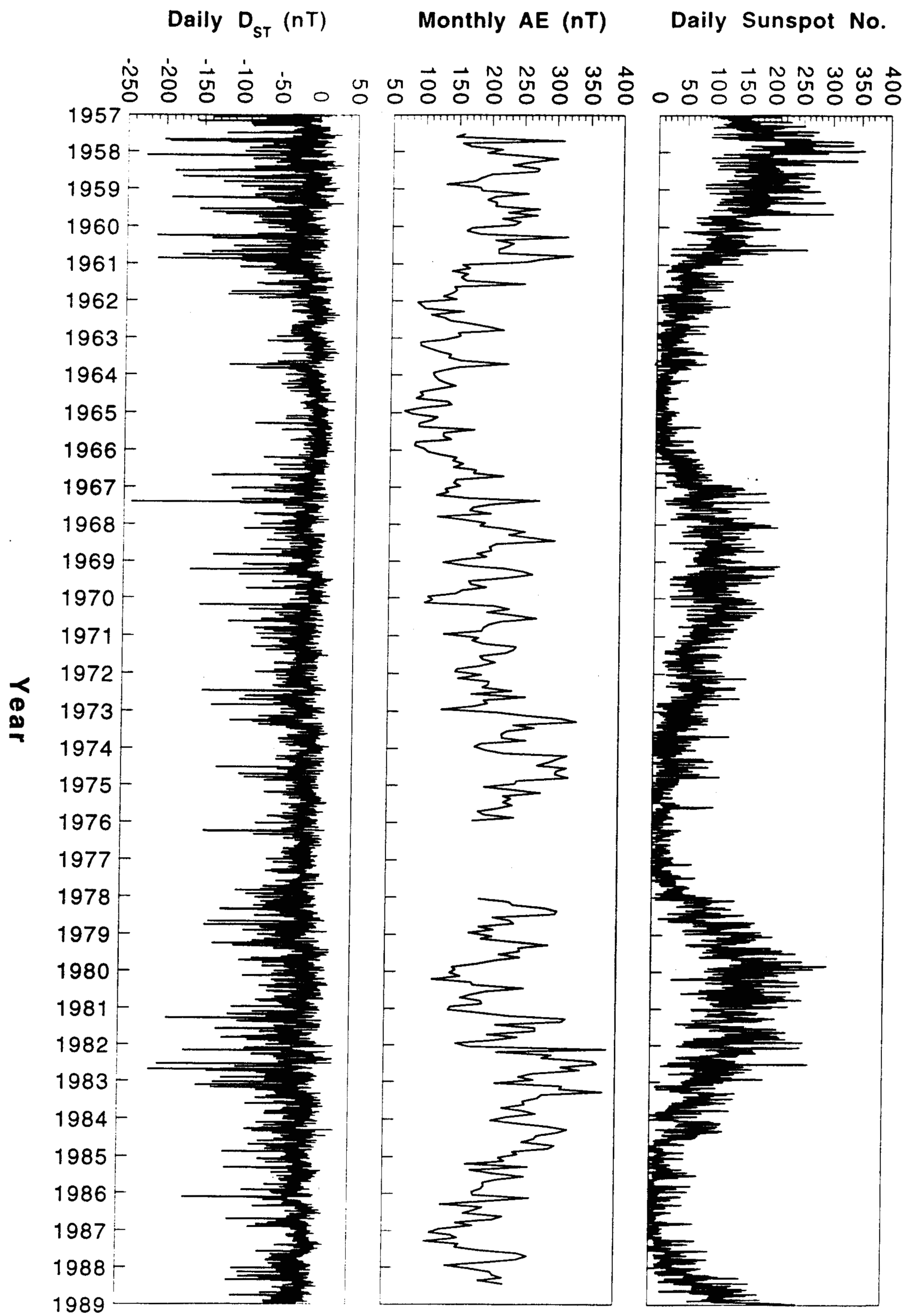
**Figure 1**. The IMP-8 interplanetary fields and AE and $D_{ST}$ indices for days 135-138, 1974. the IMF $B_S$ events lead to AE increases (substorm) and small $D_{ST}$ decreases.

**Figure 2**. The daily sunspot number, monthly average AE values, and the daily $D_{ST}$ values for 1957 to 1989.



IMP-8
May 15, 1974
Day 136
15.0
7.5
0.0
|B| (nT)
12
0
-12
$B_z$ (nT)
1200
600
0
AE (nT)
0
-20
-40
$D_{ST}$ (nT)
0000
0400
0800
1200
1600
2000
2400
UT


Daily $D_{ST}$ (nT)
Monthly AE (nT)
Daily Sunspot No.
Year
-250 -200 -150 -100 -50 0 50
50 100 150 200 250 300 350 400
0 50 100 150 200 250 300 350 400
1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989